A 320GHz Phase-Locked Transmitter with 3.3mW Radiated Power and 22.5dBm EIRP for Heterodyne THz Imaging Systems

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Non-ionizing terahertz imaging using solid-state integrated electronics has been gaining increasing attention over the past few years. However, there are currently several factors that deter the implementations of fully-integrated imaging systems. Due to the lack of low-noise amplification above 100GHz, highly compact and energy efficient transmitters are needed for practical imaging systems. In [3], a 245GHz SiGe transmitter with integrated antenna and baseband electronics was demonstrated, which indicated that for differential signals, the RPG has a transmission loss of only 0.6dB at 317GHz. To achieve the optimum voltage gain of the transistor at f0 and is critical to (i) achieve the optimum voltage gain of the transistor at f0, it is critical to (ii) achieve the optimum voltage gain of the transistor at f0, it is critical to (iii) achieve the optimum voltage gain of the transistor at f0.

In the transmitter, 16 radiators combine their power in free space. For coherency, they are injection-locked by 4 mutual-coupled VCOs. The PLL is reported effective in enhancing detection sensitivity [4]. Due to the preservation of phase-locking capability, and the highest output power and DC-to-RF efficiency (including the reflection at silicon-to-air interface) is ~50%. It is also noteworthy that the 2f0 signal is generated by the nonlinear heterojunction at the base of the HBT. Such technique recycles the fundamental oscillation power dissipated at the base, and efficiently upconverts it to 2f0. From the above analysis, it can be seen that through the synthesis and guidance of different electromagnetic wave modes, we have optimized the fundamental oscillation, harmonic generation and radiation with a very compact passive structure.

In the transmitter, 16 radiators combine their power in free space. For coherency, they are injection-locked by 4 mutual-coupled VCOs (Fig. 25.5.1). Based on differential Colpitts topology, the VCOs oscillate at 80GHz with second-harmonic extraction to drive 4 160GHz buffers. One VCO also connects to a divider chain inside a PLL. It is noteworthy that the PLL has a controllable fractional-N capability. When the transmitter pairs with a heterodyne receiver, where an identical PLL (with fractional-N disabled) is built-in to generate LO, desired RF-to-LO frequency offset (~100MHz) is obtained. In such imaging system, only one low-frequency reference clock (~32MHz) is needed.

The measurement setup is shown in Fig. 25.5.4, where the radiated spectra are measured by a WR-3 horn antenna cascaded with a VDI Even-Harmonic Mixer (EHM). It can be seen that the radiators are synchronized by the on-chip PLL. The measured output frequency is 317GHz. To eliminate the substrate wave caused by the silicon substrate, a hemispheric (radius=5mm), high-resistivity Si lens is attached on the chip backside. The measured radiation patterns with and without the lens are shown in Fig. 25.5.5, which have a directivity of 17.3dB and 13.0dB, respectively. The difference is due to the refraction at the silicon-to-air interface (without lens). Using an Erickson PM4 calorimeter, the radiated power/EIRP (with silicon lens) are measured at varying distances and radiator DC supplies. Shown in Fig. 25.5.5, the measurement is consistent with the Friis equation in far-field range above 5cm. The peak EIRP and total radiated power are 22.5dB and 5.2dB (3.3mW). Without the silicon lens, the EIRP is 13.9dB, and the radiated power only drops to 0.9dB (1.23mW), which is still higher than [1,2,7] and [8]. Finally, the micrograph of the die and a performance comparison with the state-of-the-art are given in Fig. 25.5.6. This work demonstrates fully-integrated phase-locking capability, and the highest output power and DC-to-RF efficiency among the silicon THz radiators listed in the Table.

Acknowledgements:
The authors acknowledge the Army Research Lab and National Science Foundation for their support and STMicroelectronics for silicon donation.

References:
Figure 25.5.1: Architecture of the 320GHz transmitter for heterodyne imaging systems.

Figure 25.5.2: Return-path gap radiator and its operations at $f_0$ (as two self-feeding oscillators) and $2f_0$ (as a harmonic radiator). The simulated optimum phase of the transistor (plus half RPG) at $f_0$ is also shown.

Figure 25.5.3: The EM field distribution and simulated insertion loss of the RPG structure for (left) differential oscillation at $f_0$ and (right) common-mode harmonic generation/radiation at $2f_0$.

Figure 25.5.4: Measurement setup and the measured spectra of the downconverted radiation (with and without radiator synchronization).

Figure 25.5.5: (Top) Measured radiation pattern, (bottom left) received radiation power versus distance, and (bottom right) total radiated power and DC-to-RF efficiencies at different power supplies.

Figure 25.5.6: Chip micrograph and performance comparison with other state-of-the-art silicon-based radiators in sub-THz/THz range.
Figure 25.5.7: Die micrograph of the 320GHz SiGe Transmitter.